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SOCIETAL LIFE CYCLE ASSESSMENT

Social aspects for sustainability assessment of technologies—challenges for social life cycle assessment (SLCA)

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Abstract

Purpose Technologies can contribute to sustainable development (e.g., improving living conditions) and at the same time cause sustainability problems (e.g., emissions). Decisions on alternative technologies should thus ideally be based on the principle to minimize the latter. Analyzing environmental, economic, and social aspects related to technologies supports decisions by identifying the "more sustainable" technology. This paper focuses on social issues. First, it discusses the applicability of the social life cycle assessment (SLCA) guidelines for a comparative technology analysis, taking the example of two case studies in developing countries. Indicating technologies as "sustainable" also means that they are indeed operated over the expected lifetime, which, in development projects, is often not guaranteed. Consequently, social aspects related to implementation conditions should be considered in an SLCA study as well. Thus, a second focus is laid on identifying appropriate indicators to address these aspects.

Methods First, the SLCA guidelines were examined with regard to applying this product-related approach to two real case studies (analysis of technologies/plants for water supply and for decentralized fuel production) for a comparative technology analysis. Suitable indicators are proposed. To address the second focus, a literature research on technology assessment and implementation in developing countries was conducted. Moreover, socioeconomic studies in the investigation areas of the case studies were consulted. Based on this, indicators addressing implementation conditions were identified from the SLCA guidelines and additional literature.

Results and discussion The study shows social issues and indicators found in the SLCA guidelines and considered suitable for a comparative technology analysis in the case studies. However, for a sustainability assessment of technologies, especially in developing countries, further indicators are required to address technology implementation conditions. A set of additional social indicators like reported trust in institutions or fluctuation of personnel is proposed. Though these indicators were derived based on specific case studies, they can also be suggested to other technologies and are not necessarily limited to developing countries.

Conclusions The study pointed out that an application of the SLCA guidelines considering the whole life cycle was not (yet) feasible for the case studies considered. This is mainly due to the lack of data. Regarding technology implementation, it was examined which indicators are available in this SLCA approach and which could additionally be integrated and applied. This is relevant as a potential contribution of technologies to sustainable development can only be achieved when the technologies are successfully implemented.

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1 Introduction

The concept of sustainability—encompassing the environmental, economic, and social dimensions—is nowadays addressed in numerous regional, national, and international frameworks and programs. The concept of life cycle sustainability assessment (LCSA) (Kloepffer 2007, 2008; Finkbeiner et al. 2008, 2010) combining the methods of life cycle assessment (LCA) (International Standard Organisation 2006), life cycle costing (LCC) (Swarr et al. 2011), and social life cycle assessment (SLCA) (UNEP/SETAC 2009) gains increasing attention. A framework, showing how these three methods can be used for an overarching LCSA, is available since 2011 (UNEP/SETAC 2011). Taking a life cycle perspective is crucial to avoid shifting the burden between the different life cycle stages. Analyzing potential impacts of products and identifying hotspots along their life cycles help to support decisions aiming at contributing to a sustainable development. An increasing interest to those methods is also paid in developing countries and their use as decision support tools in developing projects can be expected.

An example for that are two ongoing research projects (Integrated Water Resources Management (IWRM) and microstructured reactor for biomass-to-liquid (BtL) application, see Section 2.3) in which LCA and LCC are used as tools for sustainability analysis of technologies for providing such basic needs as water and fuel in developing countries, thus contributing to an improvement of living conditions. As a complement to LCA and LCC and against the background of the LCSA concept and decision support, this paper addresses the integration of social aspects and the identification of appropriate indicators.[1] The focus is laid on the product-related SLCA approach of the UNEP/SETAC (2009, 2011) guidelines for SLCA, further discussed in Section 2.2. Besides this, other SLCA approaches exist (e.g., Weidema 2006; Hutchins and Sutherland 2008; Jørgensen et al. 2012). Hutchins and Sutherland (2008), for example, stress the importance of considering social impacts throughout the supply chain for decision making and emphasize the influence of companies. The indicators proposed address rather the "social performance" of a region or a nation and thus do not seem appropriate for a comparative technology analysis on a product level. Weidema (2006) focuses on impact assessment, but which is not (yet) part of this study. Both approaches seem to be valuable when the goal of the study would be to assess social impacts due to a "project" (meaning to analyze how the situation was before and will be after implementing a certain technology). Of course, this is interesting and important. However, the focus of this paper is to identify indicators which are considered suitable for a comparative technology analysis on a product level as well as indicators addressing technology implementation.

The interest for the latter derives from the fact that, despite wide experience in development projects considering technology transfer, there is still a high failure rate. This is often caused by unresolved technical challenges and more often by an inadequate social framework for the use of those technologies (Nieuwenhout et al. 2001; Sahay and Avgerou 2002; Long et al. 2004; Hellpap 2009). Thus, "sustainability" of technology—when understood in terms of "lasting"—often cannot be guaranteed. Having in mind the high economic and developmental potential of developing countries and, therefore, the increasing implementation and use of technologies, it is essential to include social aspects related to technology implementation in an early stage of technology development as well as in decision-making processes for (already available) alternative technology options to avoid failing.

Currently, social aspects/issues are considered in developing projects mainly with methods and tools, such as socioeconomic studies, social impact assessment (SIA) (IAIA 1994), and training programs for the use of (new) technologies. When fully developed, the SLCA approaches will be the only social assessment methods taking into account social aspects from a life cycle perspective and thus be able to address a potential transfer of effects/impacts between the life cycle stages.

The following two main objectives of the paper are derived:

1. General discussion of the applicability of the SLCA approach proposed in the guidelines for a comparative technology analysis in the case studies considering all life cycle phases.
2. Which social issues, identified as being relevant with regard to successful (sustainable) technology implementation in two case studies, can be assessed using the SLCA guidelines approach and which should additionally be integrated?

This study follows the discussion on the applicability of the SLCA guidelines for technologies presented in Lehmann et al.

[1] Oxford (2012) defines indicator among others as "a thing that indicates the state or level of something" or as "a device providing specific information on the state or condition of something." It can be differentiated between quantitative indicators using numbers to describe an issue, qualitative indicators using words, and semiquantitative indicators that categorize qualitative indicators in a yes/no form or in a scale (e.g., low, middle, high) (e.g., UNEP/SETAC 2009, 2011). Regarding social indicators, a number of definitions exist, summarized, e.g., in Noll (2004). According to Zapf (1977, p. 236), for example, social indicators are "all data which enlighten us in some way about structures and processes, goals and achievements, values and opinions."

(2011a). The present work further specifies social indicators which are suitable for a comparative technology analysis and for addressing social aspects related to technology implementation. Also, more detailed discussion is provided regarding the assessment of social aspects along the entire life cycle. Moreover, an additional case study is included.

This work does neither seek to be a complete social assessment of technologies examined in the case studies (additional methods, e.g., SIA would be necessary to meet this objective) nor to present the full SLCA result of the technologies considered.

This paper discusses the social aspects for sustainability assessment of technologies and resulting challenges for SLCA—the evaluation of the suitability of the overarching LCSA framework for a sustainability assessment of technologies is beyond the scope of this paper.

The objects of investigation are the life cycles or parts of it (namely, the use phase, when considering technology implementation conditions) of technologies/plants for water supply and fuel conversion and not the ones of water and fuel produced (Fig. 1). Therefore, social indicators are related to these technologies and not to the products provided.

2 Methods

2.1 Research approach

Two ongoing research projects aiming at the implementation of technologies in developing countries (or regions) are used as case studies to discuss the previously mentioned questions.

First, the SLCA approach of the SLCA guidelines (UNEP/SETAC 2009) was examined with regard to applying this product-related approach to real case studies, namely, comparative analyses of alternative technology options for water supply and alternative technology designs for a microstructured reactor for fuel production in developing countries. It was discussed to what extent the life cycle perspective can actually be considered in the particular case studies as well as in studies in a similar context (see Section 3.1). Based on these findings, the SLCA guidelines and the associated methodological sheets (Benoît-Norris et al. 2011) (described in Section 2.2) were investigated to identify social issues (subcategories) and indicators that can be used for a comparative technology analysis (see Section 3.2). A list with indicators considered suitable was proposed (Table 1).

Secondly, it was examined which social aspects (subcategories and indicators) can be related to technology implementation, thus are relevant regarding the use phase of technologies (see Section 3.2). The selection of subcategories and indicators addressing implementation conditions was done based on the SLCA guidelines' stakeholder approach: stakeholders affected by the technologies' use phase are assumed to be mainly workers, consumers, and the local community (partly the society as well). From the subcategories and indicators proposed for these stakeholder groups, selected were those which somehow can be referred to the implementation of technologies. This identification was done taking into account findings from the literature: a literature research (see Section 3.3) on technology transfer and implementation (e.g., Tébar-Less and McMillan 2005), on systems analysis and technology assessment (e.g., Schultz et al. 2009; Kopfmueller et al. 2001), and on socio-economic studies in the investigation areas (e.g., Nayono 2009, unpublished; Nayono et al. 2011; Oertel 2010; Puspitasari 2009), which, for example, describe challenges while implementing a technology, was conducted. Based on the literature research, further social aspects and indicators related to technology implementation were identified and a list with additional social indicators was derived (Table 2).

2.2 SLCA guidelines—the approach and its use in practice

The SLCA approach according to the SLCA guidelines published by the UNEP/SETAC Life Cycle Initiative (LCI) (UNEP/SETAC 2009) follows the ISO standard for LCA (International Standard Organisation 2006). It consists of four main phases (goal and scope definition, life cycle inventory analysis, life cycle impact assessment, and interpretation) and assesses social and socioeconomic issues along the product life cycle to provide information on social and socioeconomic aspects to support decision making. Besides, other SLCA approaches exist and are under development (e.g., Weidema 2006; Hutchins and Sutherland 2008). A review of SLCA approaches is presented in Jørgensen et al. (2008). Jørgensen et al. (2012) describe the effects of SLCA methods, indicate three overlapping SLCA approaches, and state that the SLCA guidelines can be perceived as each of them—depending on the study's goal.

An extract of the assessment and classification system for social issues, used in the SLCA guidelines, is shown in Table 3. In the guidelines, social issues—expressed in the so-called subcategories—are classified with regard to stakeholder categories and impact categories. Stakeholders are workers, value chain actors, consumers, and society and local communities; impact[2] categories are human rights, working conditions, health and safety, cultural heritage, governance, and socioeconomic repercussions. The UNEP/SETAC LCI has published methodological sheets (so far, 31) for providing a more

[2] Within the SLCA guidelines, the term impact encompasses effects, consequences, social change processes, and social attributes. Following the concept of Vanclay (2002), in this paper, social impacts refer only to impacts that can be experienced by humans. Otherwise, the terms social aspects or social issues are used, which—when they undergo a change—may lead to impacts.

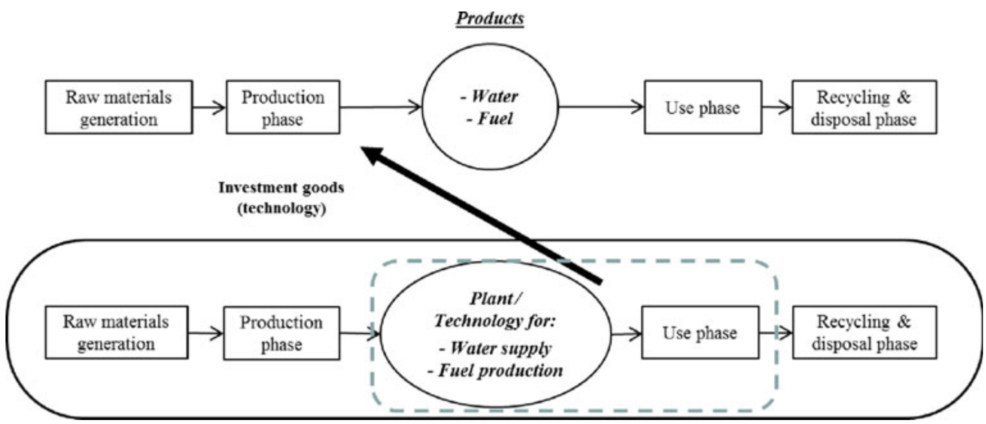

Fig. 1 Life cycle of products and technologies to produce/ provide water or fuel

practical support to the practitioners on how to assess each subcategory. They give a definition of the social issues, relate those to international instruments (conventions, agreements, and targets), describe the policy relevance (in terms of possible contribution to sustainable development), propose social indicators, and provide information on possible data sources.

So far, only few SLCA case studies exist. Case studies which follow the SLCA guidelines approach analyzed, e.g., cut roses (Franze and Ciroth 2011a), laptops (Franze and Ciroth 2011b; Prakash 2012; Ekener Petersen and Finnveden 2013), or soap (Ugaya 2012). Compared to the products addressed in these SLCA studies, the technologies (or plants) considered here and which are presented in Section 2.3 represent a different product type. With regard to a sustainability assessment of technologies, additional social indicators are required to address as well aspects related to implementation conditions.

2.3 Case studies (research projects)

Two case studies aiming at assessing the sustainability of technologies for water and fuel production in developing countries were taken as examples to examine challenges for SLCA regarding its use for technology analysis in practical case studies. The content of the first case study is the analysis of alternative technologies for water supply and wastewater treatment in an Indonesian rural region (Section 2.3.1). The second case study deals with alternative design options for a new technology for fuel production (microreactor) which is expected to have high potential in decentralized fuel production (Section 2.3.2).

According to the LCA methodology, products (technologies) are compared based on a functional unit—here, e.g., provision of a certain amount of water or fuel for a certain time (e.g., lifetime of the plant). Thus, beneficial social impacts due to an improved water or fuel supply, which result from an implementation of technologies, are the same. In other words (considering technologies as products), those social impacts in the use phase of technologies "occur when the product provides the service to the user, as specified in the functional unit of the LCA" (Dreyer et al. 2006). The social impacts (leading to improved living conditions) due to the "provided service" (water/fuel provision) are not investigated here (1) because they are the same and thus not decision relevant in a comparative study and (2) because, with "water" or "fuel", no new products are introduced to the market (as it is the case, e.g., for nanotechnologies), which (unknown) effects would be crucial to be considered.

Successful implementation depends strongly on social and institutional conditions. Those aspects relate to the operation phase (the use phase) of the technologies. Besides discussing general aspects on applying SLCA for the two case studies, the second objective is to analyze social aspects related to technology implementation and to identify indicators (both from the SLCA guidelines and other literature), which are suitable to describe these aspects. This may contribute to enhance current SLCA methodologies.

According to objective 1, defined in Section 1, this paper addresses how the SLCA guidelines can be used for comparative technology analyses using the examples of two case studies described in the succeeding sections. It does not seek to be a complete social assessment of technologies.

2.3.1 Technology analysis within an Integrated Water Resources Management project

Gunung Kidul (Java) is one of Indonesia's poorest regions suffering from water scarcity and unsatisfactory water quality, especially in the dry season (e.g., due to karst formation). The IWRM project aims at improving the standard of living by the development and implementation of appropriate technologies for water supply, distribution, and treatment and wastewater management (IWRM 2011). The issue of water supply was addressed by implementing an improved technology to pump water from underground karst rivers. The new technology employs an underground dam and hydropower plant to increase the volume of supplied water using renewable energy (hydropower) instead of the previously used technology based on fossil fuels. Feasible

Table 1 Subcategories (affected stakeholders, in brackets) and indicators from SLCA guidelines (UNEP/SETAC 2009) and methodological sheets (Benoît-Norris et al. 2011) that (1) are suitable for a comparative technology analysis (thus are specific for a technology) and (2) address aspects related to technology implementation (adapted from Lehmann et al. 2011a, b)

		Subcategories (affected stakeholders)	Inventory indicators
Social aspects suitable for a comparative technology analysis[a]	Social benefits	Local employment (local community), e.g., how local employment is directly or indirectly affected by alternative technologies	Number of people employed locally to operate the technology
	Working conditions (depend both on organizational/institutional conditions and on technologies/processes)	Hours of work (workers)	Effort to provide a specific amount of water/fuel[b]
		Health and safety (workers), e.g., health damages by, e.g., equipment accidents, pollution, and benefits	Preventive measures, emergency protocols exist regarding accidents and injuries
		Safe and healthy living conditions (local community)	Presence/strength of laws on construction safety regulations
Social aspects related to technology implementation[a]	Acceptance of technologies (relevant for successful technology transfer and use of technologies)	Community engagement (local community), e.g., inclusion in decision processes	Public trust of politicians
		Cultural heritage (local community)	Is relevant information available to community members in their spoken language
		Feedback mechanism (consumers)	Mechanism for consumers exist to provide feedback
		Corruption (society[c]), e.g., is corruption prevalent in the organizations/institutions responsible for the technologies?	Risk of corruption in sector
	Framework conditions for successful technology implementation	Access to immaterial resources (local community), e.g., improved access to education, transferring technology and skills to community	Presence/strength of community education initiatives
		Access to material resources (local community), e.g., awareness of aspects related to resources use; measures to embed this in sustainable development	Has a project-related infrastructure with mutual community access and benefit been developed
		Public commitment to sustainability issues (society), e.g., awareness of sustainability issues; willingness to contribute to sustainable development	Presence of publicly available documents (promises, agreements) on sustainability issues

The subcategories and indicators were selected based on the two case studies but can be suggested to other technologies as well

[a] Indicators within the subcategories social benefits and working conditions can be specific for a certain technology and, thus, be useful for a comparative analysis. Social aspects related to technology implementation include acceptance and framework conditions. These differentiations were introduced in column 2 to show the relation to the subcategories

[b] This indicator is specific for the case studies; for example, alternative technologies for decentralized water treatment (on household level) can have different capacities, leading to different hours of work necessary to provide a certain amount of water. In that case, the hours of work do not depend on, e.g., organizational conditions, but are related to (and specific for) the technology

[c] Here, this indicator refers rather to the stakeholder group local community than to society

alternative strategies for water treatment and wastewater management that could be implemented in the area of Gunung Kidul are currently under investigation.

2.3.2 Decentralized fuel production with new technology

The technology examined is a microstructured reactor for gas to liquid fuel conversion via Fischer–Tropsch (FT) synthesis. The process produces synthetic fuel, typically from coal, natural gas, or biomass previously converted to synthetic gas. Compared to conventional fuel production plants, the microreactor shows the following characteristics: small size (<1,000 kg), low investment costs (several thousand dollars), and appropriateness for small amounts of fuel (1–1,000 kg product/day) and for remote location. Today, fuel and synthetic fuel are produced in centralized large-scale plants (e.g., Oryx GTL, Qatar), with the exception of small, decentralized experimental and commercial plants (Velocys, Inc.). The properties of the microstructured

Table 2 List of additional social indicators referring to implementation of technologies

(Social) inventory indicator	Unit of measurement
Are responsibilities (e.g., responsible institutions) for the technologies clearly defined (e.g., for water supply, distribution, wastewater disposal)	Semiquantitative (yes/no)
Number of institutions which are responsible for a technology (construction, operation, and maintenance)	Quantitative
Reported trust in social institutions	Qualitative
	Semiquantitative (low, medium, high)
Number and percentage of successfully implemented technologies (e.g., within a development aid project) in the sector in the region/country/sector	Quantitative (e.g., practical lifetime/theoretical lifetime in percent)
	Semiquantitative (low, medium, high)
Response time to repair broken devices (e.g., a pipe)	Quantitative (hour, day, months)
	Semiquantitative, qualitative (short, medium, long)
Amount of fluctuation of the personnel (relevant regarding knowledge transfer)	Semiquantitative (low, medium, high)
Skills/knowledge required to construct/operate/maintain the technology	Semiquantitative (low, medium, high)
Existence of continuously annual investment for water sector[a]	Semiquantitative (yes/no)
Amount of annual investment in the water sector[a]	Quantitative
Existence of an independent body for water price determination[a]	Semiquantitative (yes/no)
Existence of infrastructure for distribute/sell the product of/service provided by the technology	Semiquantitative (yes/no)

The indicators were selected based on the two cases studies on water and fuel provision but can be suggested to other technologies as well and are not necessarily limited to developing countries. The indicators address (and raise awareness) of issues related to a successful technology implementation (e.g., defined responsibilities, knowledge/capacity or financing). The indicators as such are not directional; the interpretation depends on the context and/or can be interpreted in combination with other indicators, for example, a high fluctuation of personnel more likely affects the operation/maintenance of a technology which requires high skilled personnel. Sources: Saleth and Dinar (1999, adapted by Nayono 2009, unpublished; Nayono et al. 2011); Tébar-Less and McMillan 2005; Renn et al. (2009); Puspitasari (2009); Oertel (2010, adapted from Lehmann et al. 2011a)

[a] These indicators are specific for the water sector but can easily be adapted to other sectors as well

reactor strongly support a new concept of fuel production, characterized by decentralized production of small amounts, by-product utilization, and private ownership. While the development of the FT microstructured reactor is still ongoing, the example of small, decentralized BtL plants in the rural area of developing countries is taken for life cycle analysis. Different design options for the microreactor are tested within this project.

3 Results and discussion

3.1 Application of SLCA guidelines to describe social issues in two real case studies

Most of the social issues described in the methodological sheets by subcategories and indicators refer to the behavior/conduct of organizations (companies and institutions). Only few social issues can be allocated directly to a process/product, which means that "there is a causal link between process and (…) impact" (Jørgensen et al. 2008).

Regarding the IWRM project, specific organizations are only known for the foreground system (production/construction phase and use phase of technologies[3]). Involved institutions are the construction agency, agency for water supply and water distribution, and health agency. As they are the same for water supply technologies (which depend on institutions, such as the underground hydropower plant and the diesel pumps), social issues related to the institutions' behavior (e.g., workers' rights) are the same. They can principally be determined and would certainly deliver useful information for a social assessment of technologies. However, for a comparative study on alternative technologies in this particular case study, it is assumed that they are not decision relevant because they are the same and because it is not discussed *if* a technology should be implemented but which alternative technology option. Hence, decision relevant would be those social issues that can be directly allocated to the technologies (e.g., working conditions during construction and operation of the respective technologies (see Section 3.2; Table 1). The same accounts for the second case study which examines different design options of a technology for fuel production.

[3] The lifetime of the technologies is assumed to be about 50–100 years. As data are not available with regard to if and how technologies will be deconstructed/disposed, this life cycle stage is excluded from the study.

Table 3 Assessment system for social issues, adapted from UNEP/SETAC (2009)—example, stakeholder group workers

	Impact categories	Subcategories (social issue)	Inventory Indicators (social indicator)	Inventory data
Workers	Working conditions	Fair salary	Minimum wage by country	
		Child labor	Percentage of children working in a country	

It should be emphasized that the simplifications introduced here for a comparative analysis do not imply that the analysis of social issues related to the institution's behavior is not important. It definitely is, especially as most of the social issues refer to the behavior of organizations. An analysis of these aspects could, e.g., reveal potentials for improving the social conditions in a certain organization. However, from a decision support perspective regarding alternative technology options (technology designs)—assuming that responsible institutions are the same (and/or not known)—this could be considered as a second step, once a technology option is selected.

As described previously, most social aspects refer to the behavior of organizations: To address the life cycle, thus including the supply chain (background system, e.g., transport, materials, energy for construction, and use of technologies), ideally, an assessment of all organizations along the supply chain would be necessary. The relevance of social impacts throughout the supply chain for decision making and the influence of companies are also stated, e.g., in Hutchins and Sutherland (2008) (see Section 1). But so far, no SLCA case study is available which covers the complexity of the supply chain.

In the two case studies considered here, the involved organizations are not yet known. Thus, site-specific social aspects throughout the supply chain could not be assessed. However, generic data on social aspects are available. For some social issues addressed in the SLCA guidelines (e.g., equal opportunities, risk of child labor, excessive work), the Social Hotspot Database (SHDB 2009), for example, provides information on sector and/or country level regarding the risk or opportunity that this social aspect occurs. Following the perspective of a comparative technology assessment, it could be useful (as a first step) to analyze social aspects related to sectors/countries involved in the technologies' life cycle and which are likely to be different for the alternative technology options/designs. Regarding the IWRM case study, the main differences of alternative water supply technologies relate to the amount and type of energy (electricity, diesel) used for operating the technologies. With regard to the fuel production case study, the main differences between the alternative design options refer to the energy and raw materials required in the manufacturing of a BtL plant with desired output. As an example, social risks related to the oil and electricity sector in Indonesia were determined within the IWRM case study using the SHDB. Social risks in the background system of the fuel production technology were not determined because technology development is in early research and development and decisions towards energy and raw materials are not specified yet.

The analysis of the Indonesian oil and electricity sector based on the SHDB showed medium to very high risks or opportunities that social aspects occur. It also revealed that the identified risks/opportunities in the sectors are often the same, that data are missing for one of the two sectors (status as of February 2013), and that social risks/opportunities are thus partly or are available only on a country level, not on a sector level. Hence, the information obtained for these parts of the supply chain cannot be used for a straightforward direct comparison on a sector level. As oil (for diesel production and partly also used for electricity) is imported from other countries (e.g., Saudi Arabia, Iran, Yemen), country-specific sector data have to be taken into account as well. As an example, social risks in the oil sector of the exporting countries were determined. Due to a lack of data (especially for Saudi Arabia), no clear results could be obtained. Generally, these current weaknesses can be solved by further development of the SHDB or by increasing data availability in general. But even if full sector data was available, it is questionable to what extent the information gained can be used for a comparative analysis: A high social risk for forced labor in the transport sector, for example, does not mean that forced labor actually occurs in the transport companies involved in a particular case study. However, the SHDB can be used to identify potential social hotspots, which could be further analyzed with site-specific data, once they are available. If the site-specific data would show that, e.g., forced labor does not occur, the consequent social assessment is positive and the risk is transformed into an opportunity.

The challenges described here for the assessment of the supply chain are derived from the IWRM case study. However, similar challenges can be expected in the fuel production case study and generally in case studies on technology analysis in a similar context (e.g., studies within ongoing projects in developing countries).

With regard to evaluating social aspects and impacts or social risks/opportunities analyzed based on the SLCA guidelines and the SHDB, the life cycle attribute assessment could be considered (e.g., UNEP/SETAC 2009). By using this assessment, the percentage of a supply chain with a certain social impact, risk, or opportunity could be determined. Life

cycle attribute assessment was not considered here, as impact assessment was beyond the scope of this study.

A proposal for a detailed methodological and practical approach on assessing the supply chain in a real SLCA case study based on the data provided from the SHDB is currently prepared by Martínez Blanco et al. (2013). This study analyzes the social risks related to different types of fertilizers. Following the approach of the life cycle attribute assessment, the amount of working time spent on each unit process was used to score the relevance of each process. Though the results obtained in this case study are based mainly on sector and country risks and generic data, the study can be seen as a first step to integrate social aspect in a practical SLCA case study, taking into account the whole supply chain.

3.2 Subcategories and indicators from the SLCA guidelines suitable for a comparative technology analysis and for addressing technology implementation conditions

The methodological sheets propose numerous subcategories and indicators to describe various social issues on different stakeholder groups. Table 1 collects the proposals of the authors regarding those subcategories which can be (1) used for a comparative technology analysis and (2) to describe implementation conditions of technologies. Based on the findings described in Section 3.1, those social issues are considered suitable for a comparative analysis which are specific for the technologies, that means for which a "causal link between process and impact" (Jørgensen et al. 2008) exists. This was found only for aspects related to working conditions and for local employment. Hence, the stakeholders affected are mainly workers. Local community is addressed as well, as, for example, the number of jobs needed/created may differ between alternative technologies. To identify social issues addressing technology implementation, the SLCA guidelines where examined regarding subcategories which can be referred to the use phase (the relevant phase for technology implementation) and which can be related to the implementation of technologies. Seven subcategories were identified, mainly describing two general aspects, namely, acceptance of technologies and framework conditions for successful technology implementation. Acceptance includes aspects such as involvement of the community in decision processes in order to consider their needs or expectations regarding (alternative) technologies. Framework conditions include, for example, the access to material resources (e.g., infrastructure) or the awareness of sustainability issues of the local community/society. In addition to the subcategories from the SLCA guidelines, Table 1 lists exemplary indicators proposed for the subcategories in the corresponding methodological sheets (Benoît-Norris et al. 2011). The subcategories and indicators presented in Table 1 describe both static features of the situation in the investigation area (e.g., trust in institutions), which are relevant regarding a successful implementation of technologies as well as specific features of the technologies[4] (e.g., health and safety aspects or number of people needed to operate the technologies). The indicators proposed are neither limited to the technologies examined in the case studies nor to developing countries. They can be suggested to other technologies and be used in different contexts as well.

3.3 Proposal of additional social indicators related to implementation conditions of technologies

The assessment of social issues often requires context-specific social indicators. Hence, besides the indicators proposed in the SLCA guidelines, additional ones are needed to address social aspects relevant for sustainability analysis in the considered case studies. Therefore, the literature has been examined for identifying social aspects and indicators mentioned in relation to the terms "technologies," "sustainability assessment," as well as "developing countries." Generally, a huge amount of social indicators can be found in the literature for describing aspects related to the matter of human health, human well-being, quality of life, living conditions, justice, and contribution to social wealth or social development, namely, the social dimension of sustainability. Thus, according to Carrera and Mack (2010), Meadows (1998), and Bauler (2007), the challenge is not to develop new indicators, but to find the most adequate ones. According to Carrera and Mack (2010), "a widely accepted theory for the measurement of social impact (…) or a coherent theory of what matters in society" does not exist so far. For example, Christian (1974) listed social concerns and social indicators with the aim to gain an internationally comparable list of well-being indicators, Finkbeiner et al. (2010) analyzed social indicators with regard to its product relation and applicability. Renn et al. (2012) proposed a list with social indicators as part of the PROSUITE project which aims at prospective sustainability assessment of technologies. Social indicators, e.g., for describing political and institutional conditions, are represented in the Integrative Sustainability Concept of the Helmholtz Association (Kopfmueller et al. 2001; Schultz et al. 2009). Due to the complexity of the "social dimension of sustainability" and various perspectives and focuses, the

[4] Similarly to Vanclay (2002), Macombe et al. (2011) emphasize the difference between state and change when talking about social impacts. Depending on the perspective, the specific features of technologies addressed here can be both understood as consequences of (or changes due to) the implementation of the technologies as well as state features of the technologies. The latter are considered relevant regarding a comparative technology analysis.

amount and type of social indicators can vary significantly within the approaches.

Having in mind that technologies can potentially contribute to a sustainable development (e.g., by providing water and fuel) only when they are successfully implemented (see also Section 2.3), the focus was laid on identifying social indicators that address aspects related to technology implementation. These indicators were selected based on literature review and challenges and problems mentioned related to technology implementation within projects in developing countries and specifically in the two case studies. For example, challenges while implementing technologies within the IWRM project occurred because it was partly not clear which institution was responsible for the technology. Challenges identified regarding the operation of technologies were the fluctuation of personnel and the loss of knowledge. With regard to the fuel production case study, important aspects are the operator's knowledge about the technology (operation control, handling breakdowns, and maintenance) and available distribution networks for the produced fuel.

Indicators addressing those aspects are reflected in a list of additional indicators shown in Table 2. This list does not claim to be complete, but it emphasizes important social issues which should be considered when SLCA studies are conducted to analyze sustainability aspects of technologies. Though the indicators were selected based on the case studies, most of them can generally also be suggested to other technologies and they are not necessarily limited to studies in developing countries. They can be used for analyzing alternative technology options for a certain region (like, e.g., in the IWRM case study) as well as for addressing varying conditions for technology implementation in different regions.

With regard to technology implementation in the case studies, the attitude of the local community towards an institution (e.g., acceptance and trust), responsible for the technology, should be considered. Also of high relevance are information regarding institutional capacities and linkages (e.g., Saleth and Dinar 1999; Tébar-Less and McMillan 2005; Renn et al. 2009) and knowledge on whether respective responsibilities, e.g., for operation and maintenance, are indeed clearly defined (Puspitasari 2009). In that context (and if, for example, institutions are responsible for the technologies), an indicator describing the general "dependency" of a technology on an institution (e.g., number of responsible institutions) can be relevant with regard to decisions on decentralized/centralized technological options. If, for example, the assessment shows that people have low trust in institutions and/or if it is not clear which institution is actually responsible for, e.g., maintenance issues, a technology that depends on less (or no) institution would be recommendable.

The indicator "percentage of successfully implemented technologies in the investigations areas", can provide a general idea regarding chances and challenges related to technology implementation. Clearly defined responsibilities, continuously investment, or e.g., short response times to repair broken devices are crucial regarding the operation and maintenance of technologies. Moreover, the requirements to construct, to operate, and to maintain the technologies, as well as the amount of fluctuation of personnel, should be addressed by indicators. This is important as a proper maintenance and operation of technologies can be affected if the requirements are not adapted to skills and knowledge available (or if appropriate measures for capacity building are not provided) (e.g., Saleth and Dinar 1999). Closely related to this is also a high fluctuation of personnel, which can indicate a loss of knowledge (Oertel 2010). Social indicators related to infrastructure (e.g., existence of infrastructure to distribute/sell products from the technology) are important for decision makers and correspond indirectly to the potential of successful technology implementation. If there is, for example, no distribution structure for decentralized fuel production, the owners of the plant (e.g., private persons) cannot sell their products, earn no money, and therefore, would not buy the technology. Those infrastructural issues are important for decision makers for obtaining information about additional requirements needed.

According to Zapf (1977, p. 236), social indicators are "all data which enlighten us in some way about structures and processes, goals and achievements, values and opinions." As the indicators listed previously can deliver useful information regarding the situation and the conditions in the investigation area where the technologies are intended to be implemented, they are here proposed as additional indicators for sustainability assessment of technologies.

4 Conclusions and outlook

This paper discusses the objectives, methodologies, and challenges related to SLCA of technologies within the context of a sustainability assessment of technologies based on two case studies. The analysis of technologies is conducted from a product-orientated and a life cycle-orientated perspective. It is here understood as analysis of social issues related directly to the technology not to the services they provide, such as fuel and water provision.

Since technologies can be seen as products, the SLCA approach proposed in the SLCA guidelines is in principle suitable for analyzing social issues. However, when trying to apply it for comparative technology analyses in two real case studies, high challenges became obvious, mainly induced by the facts that (1) the technologies investigated here are (at least partly) still in the development phase and that (2) they are intended to be implemented in developing countries. Both go along with a lack of data. The first

challenge occurs whenever new technologies are developed; the second one refers to the fact that data availability in developing countries is currently (at least in the case studies considered) still poor (e.g., regarding sector-specific data provided for Indonesia in the SHDB). However, this is not a principal challenge—it could be mastered with improved future databases.

For now, in the case studies considered, companies and institutions involved especially in the supply chain of the technologies are hardly known. As social impacts are mainly due to the company's conduct (Jørgensen et al. 2008), a practical SLCA case study considering the whole life cycle was not (yet) feasible here.

Taking into account the entire life cycle (e.g., supply chain) is of major relevance for decision processes, and further research and improved databases are needed. With regard to the case studies, a next step could be that, once, when more information on the supply chain is available (e.g., when a technology option is implemented), further SLCA studies will be conducted. The results could be used to identify improvement potential in supplying companies and/or to decide for a certain supplier.[5] For the operation phase of the technologies, involved companies and institutions are at least partly known. But as they are the same for the alternative technologies and as the focus is a comparative analysis, the indicators proposed for technology analysis in this paper focus on describing aspects which are specific for technologies and independent on the company's conduct. The choice of suitable indicators for comparative technology analysis is thus another main challenge; only few indicators could be identified from the SLCA guidelines.

The second focus of the study was laid on the question which relevant social issues describing technology implementation conditions are addressed in the SLCA guidelines and which could additionally be integrated. This was examined because a literature review, as well as experiences from the case studies, highlighted that a comprehensive assessment of the social dimension of sustainability requires the consideration of additional criteria to tackle social issues related to technologies in developing countries. Implementation conditions include various aspects (e.g., economic, managerial, and technical aspects). One can argue that those issues as well as the discussed object of investigation (technologies) are outside the scope of current SLCA methodology (thus, also outside the scope of the LCSA framework) and that other tools like the SIA (IAIA 1994) might be more appropriate. However, indicators normally derived by SIA can serve to broaden current SLCA by including additional indicators addressing these aspects related to the use phase of technologies. With regard to implementation conditions, it should be strongly emphasized here that the intention of SLCA is not to discuss whether or not the technologies should be implemented. Also, it should be noted that the proposed indicator set addressing technology implementation is of course not complete. But it raises awareness on important social issues which should be considered in SLCA studies conducted within, e.g., an LCSA study of technologies. Generally, a comprehensive sustainability assessment of technologies requires a complementary use of various tools on various different levels (not just the product level). Exemplary tools are SIA, stakeholder analysis, environmental impact assessment, risk assessment, or cost–benefit analysis. However, the focus of this paper is the SLCA approach within the product-related LCSA framework as one tool within sustainability assessment of technologies. To establish SLCA as a useful and applicable tool to support decisions, further case studies are needed. This would consequently also contribute to increase the use of LCSA as a tool for sustainability assessment of products. As the contribution of technologies to sustainable development—by their function/the service provided (e.g., improvement of living conditions by improved water supply)—can only be achieved when the technologies are successfully implemented, the consideration of implementation conditions within technology analyses is of utmost importance. This of course is not only related to studies conducted within developing countries, as implementation conditions are always a critical aspect. However, the effects of a successful (or not successful) technology implementation (e.g., when the aim is to provide basic needs such as water) might be more tangible in developing countries than in developed countries. Hence, the consideration of those aspects should be mandatory in SLCA analyses conducted within such context.

[5] This is challenging as well because the evaluation of impacts resulting from a decision for a certain company or product also requires the evaluation of the impacts resulting from the "non-implemented product" life cycle have to be assessed as well (Jørgensen et al. 2010).

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